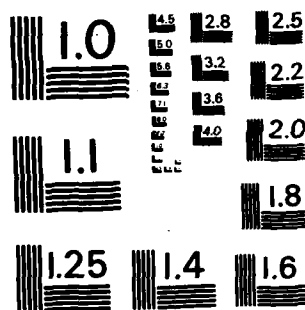


VOLUME BACKSCATTERING ATLAS AT 35KHZ(U) ROYAL  
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**VOLUME BACKSCATTERING ATLAS AT 3.5khz**

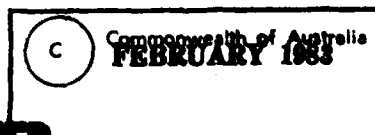
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RANRL TECHNICAL MEMORANDUM (EXTERNAL) NO. 1/83

VOLUME BACKSCATTERING ATLAS AT 3.5 kHz

ANNE F. QUILL



ABSTRACT

A comprehensive atlas is presented listing the diel, spatial and seasonal acoustic scattering data obtained with volume reverberation experiments in deep ocean areas at the acoustic frequency of 3.5 kHz.

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## 1. INTRODUCTION

In deep oceans volume reverberation will frequently be the dominant "background" level against which underwater targets are to be detected by active sonar. This technical memorandum compiles the existing available data on volume reverberation levels at 3.5 kHz for each of the world's oceans. The variations that are known to occur as a result of geographic position, season and time of day are described.

Quantitative and qualitative acoustical and biological sampling have been done in many widely separated oceanic regions. The bulk of the quantitative acoustic data have been obtained using explosive sources although some experiments have used CW - pulse transmissions from downward-looking directional transducers. This latter technique is more time consuming and more limited in frequency coverage but gives details of the variation in scattering strength as a function of depth. (This detailed information is not usually available with the explosive method).

Sampling of mesopelagic fish populations shows seasonal variation even in tropical and sub-tropical waters and associated with this, seasonal variation has also been observed in both size distribution and biomass of individual species and of the total mesopelagic assemblage (Gibbs et al, 1971). In temperate waters seasonal variations have also been observed (Pearcy, 1966). In terms of acoustical investigations data related to seasonal variation are few and partly contradictory. Haigh (1971) and Ponomareva (1974) found only negligible seasonal variations during acoustic studies of deep scattering layers while Donaldson and Pearcy (1972) found more pronounced variation.

The volume reverberation will be considered in terms of the scattering strength of the water column. The column strength equals the integral of the volume scattering coefficient over the depth between boundaries of the layer.

## 2. PARAMETERS

- (a) Volume (back) scattering strength  $S_v$  is the parameter which is most commonly used to describe backscattering. It is the target strength of unit volume of water.

$$\text{i.e. } S_v = 10 \log \frac{I_{\text{scat}}}{I_{\text{inc}}} \quad (1)$$

where  $S_v$  is the volume scattering strength in decibels,

$I_{\text{scat}}$  is the scattered intensity at unit distance from a unit volume of water,

and  $I_{\text{inc}}$  is the incident intensity at the unit volume of water.

The dimension of  $S_v$  is  $\text{length}^{-1}$ .

Examples of two measured volume backscattering strength "profiles"

(as a function of depth) are shown in fig. 1. We see that

$S_v (= 10 \log s_v)$  can vary by 30 dB from one depth to another.

- (b) Average Scattering Strength

Published data (e.g. Hall 1973, 1975) have also been expressed average scattering strengths  $\bar{s}(r)$ . This parameter is defined by

$$\bar{s}(r) = \frac{1}{r} \int_0^r s_v(z) dz \quad (2)$$

Here  $\bar{s}(r)$  is the average scattering strength in the depth interval

$$0 < z < r$$

and  $z$  is the depth in metres.

The values of  $\bar{S} (= 10 \log \bar{s})$  for the profiles shown in Fig. 1 are - 83 dB re  $\text{m}^{-1}$  (day) and - 80 dB re  $\text{m}^{-1}$  (night).

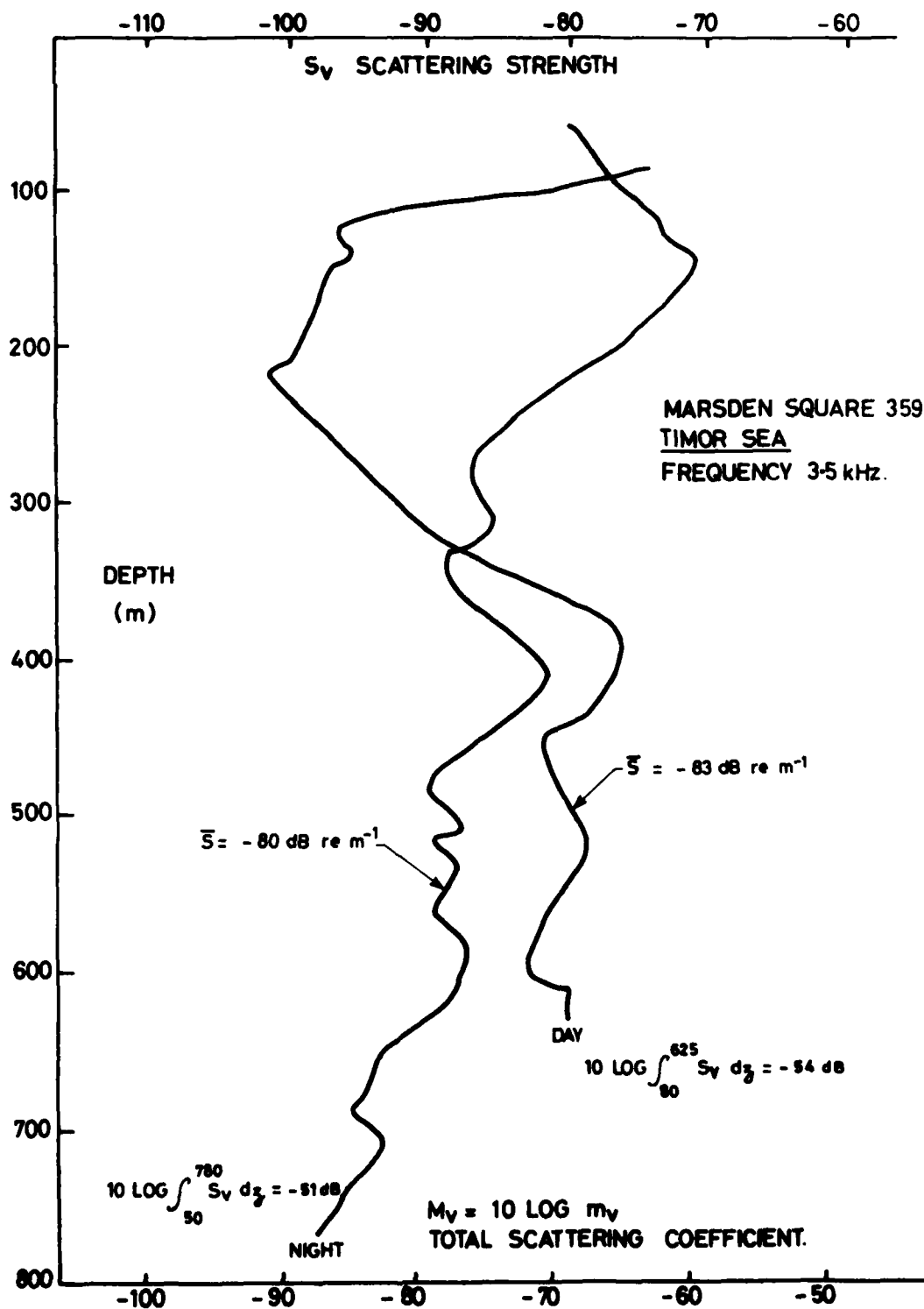


Fig. 1. The scattering units, scattering strength, scattering coefficient and column strength for Marsden Square 359 at 3.5 kHz.

- (c) Column Scattering Strength  $s_c$  is given by

$$s_c(r) = \int_0^r s_v(z) dz \quad (3)$$

and  $s_c$  is a dimensionless parameter.

The conventional logarithmic measure is  $S_c (= 10 \log s_c)$  in decibels.

Data in this technical memorandum are given as column strength,  $S_c$ . The column strength is the total target strength of the scatterers in a column of specified length and unit cross section. It is obtained by integration over the depth of the measurements. For the papers surveyed, the minimum integration limit has been 750m, and the most common integration limit is 1000m. The values of  $S_c$  for the profiles in fig. 1 (neglecting the near surface region, which may be significant) are - 54 dB (day) and - 51 dB (night).

- (d) Scattering Coefficient (or Cross-Section)

In addition, some experimenters measure volume scattering in units of  $M_v$ , the (total) scattering coefficient per unit volume. The relationship between the volume backscattering strengths ( $S_v$ ) and the total scattering coefficient is

$$s_v = \frac{M_v}{4\pi} \quad (4)$$

$$\begin{aligned} S_v &= 10 \log M_v - 10 \log 4\pi \\ &= M_v - 11 \text{ dB} \end{aligned} \quad (5)$$

where  $M_v = 10 \log m_v$

and  $S_v = 10 \log s_v$ .

For this report, any values of  $M_v$  have been converted to  $S_v$  (and then  $S_c$ ), using Eqn (5).

### 3. DESCRIPTION OF EXPERIMENTAL PROCEDURE AND DATA ACQUISITION

#### (a) Explosive Method

Scattering strength measurements are often made using explosive charges fired near the surface as an acoustic source. A hydrophone suspended close to the firing point is used to detect the backscattered returns. The hydrophone can be directional, but the experiments using explosive sources that have been reported have all employed omnidirectional hydrophones. The reverberation is produced by scattering within an expanding hemispherical shell corresponding to the shock wave of the explosion. In many cases observation of the decaying intensity of the returned sound for several seconds enables information on the scattering characteristics at almost any required depth to be obtained. Results at a frequency of 3.5 kHz have been obtained by several experimenters by simply filtering the reverberation at the desired frequency. In the case of those experiments where one-third-octave analyses were done, the level at 3.5 kHz was interpolated from the results obtained at 3.15 kHz and 4 kHz.

It may be shown (Hall, 1971) that the reverberation intensity

(i) from the hemispherical shock wave at range  $r$  is given by (ignoring absorption)

$$i(t) = 4\pi c e_0 s_c / r^3 \quad (6)$$

where  $c$  is the average speed of sound in the medium;

$e_0$  is the energy-flux at unit distance from the source;

$t$  is the time at which the reverberation is measured ( $r = \frac{1}{2} ct$ ).

(b) C.W. Method

This technique utilizes a directional source transmitting at a frequency of 3.5 kHz orientated vertically downward at approximately 2m below the surface. Highly directional transducers permit discrimination against unwanted interference such as surface reverberation, ship noise, or volume reverberation from a wide spread of depths.

The instantaneous scattering volume ensonified at range  $r$  is estimated from the pulse length and the beamwidth. Allowing for attenuation and spreading loss, the average scattering strength ( $\bar{s}$ ) of a cubic metre of this volume can then be found. As such  $s_v$  is independent of propagation loss and equipment parameters and is suitable for temporal, spatial and geographical comparisons of acoustic scattering. A weakness of this method is that the scattering close to the sea-surface is not measured (due to the non-zero length of the acoustic pulse). The various techniques which are commonly used for volume reverberation experiments are shown in Fig 2.

(c) Maraden Squares

A convenient way of dividing the globe into small manageable zones is by means of Maraden Squares (MS). The numbering system is given in Fig 3, which is reproduced from Hogben and Lumb (1967).

4. RESULTS(a) Diel Variation

Day column strengths are commonly taken between 0900 and 1500 hours solar time. Night column strengths are usually taken to be between 2100 and 0300 hours solar time. The results in each Maraden Square are presented in Tables 1 and 2 for day and night respectively. The latitude shown in each square is that of the middle of the square. Note that all tabled values for  $S_c$  should be read as

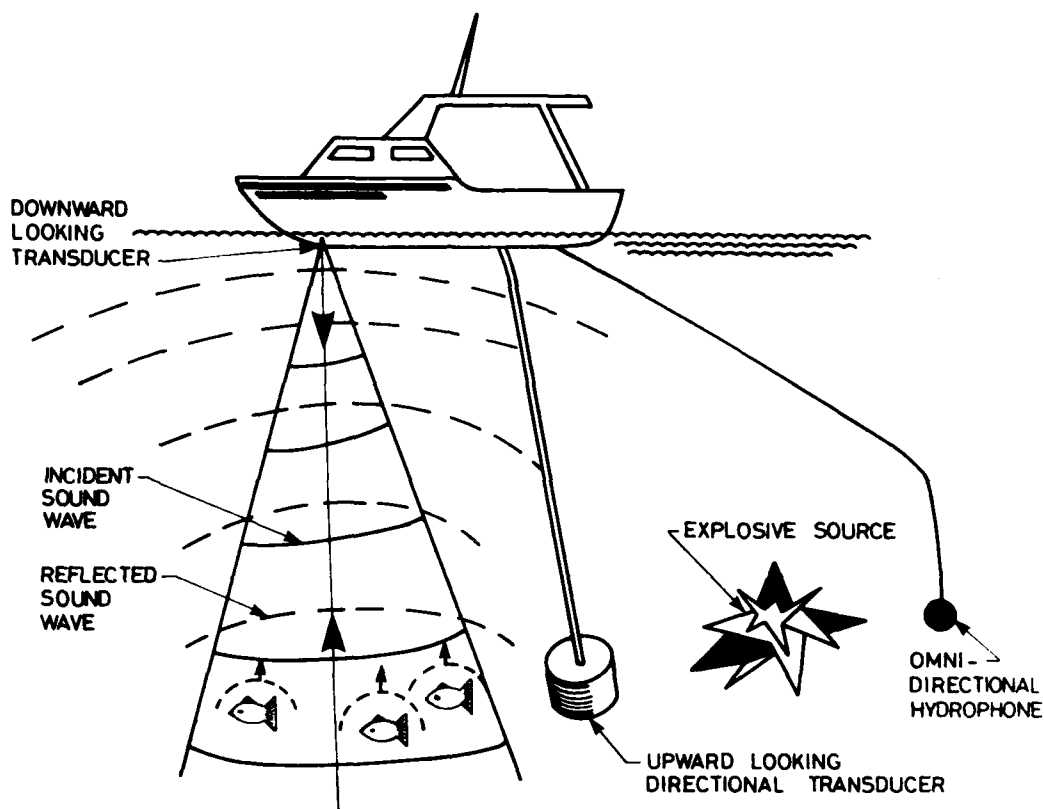


Fig. 2. Scheme of acoustic measurement techniques commonly used in volume reverberation experiments.

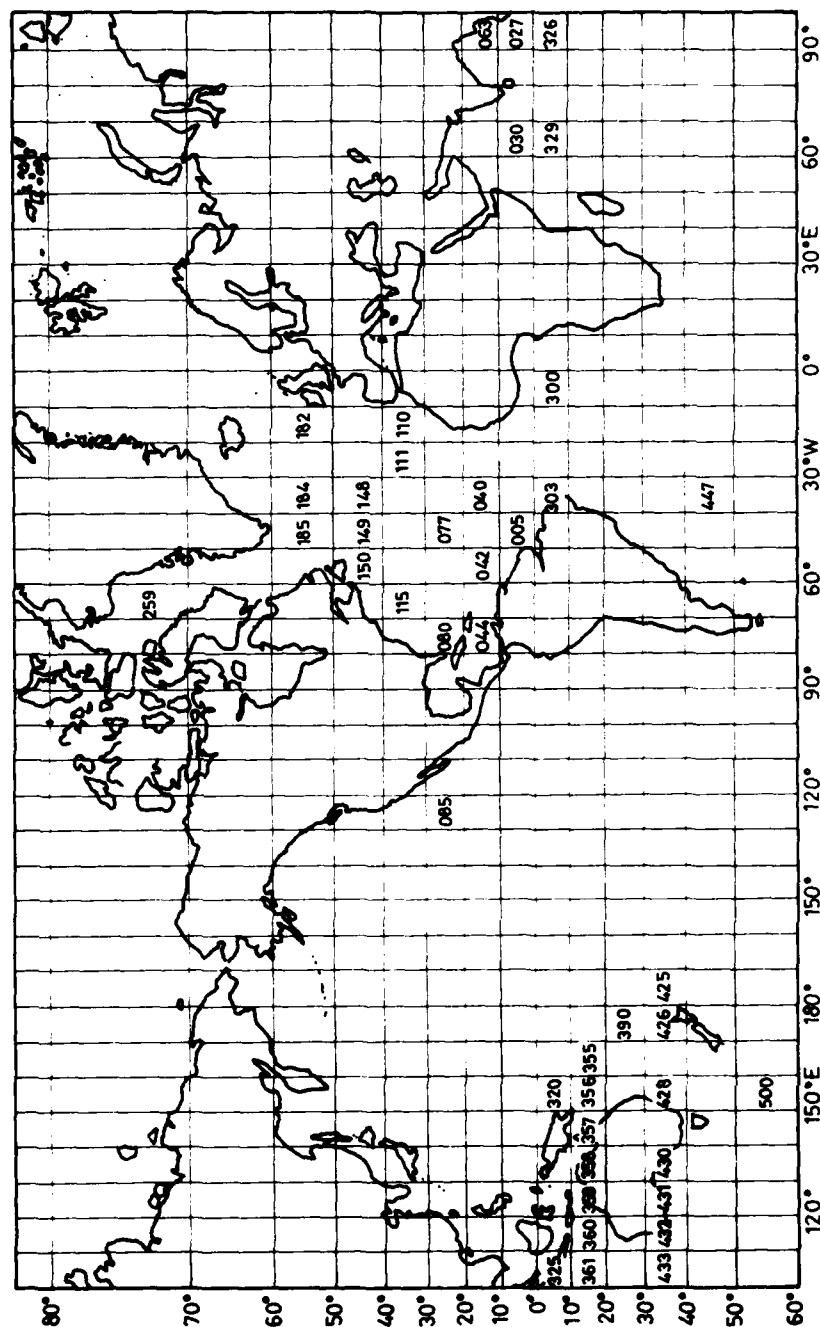


Fig. 3. Marsden Square Chart.

TABLE 1

DAY COLUMN STRENGTHS IN MARSDEN SQUARE ORDER

MARSDEN SQUARE	LATITUDE	SEASON	COLUMN STRENGTH (NEGATIVE)	GENERAL LOCATION	REFERENCE
005	5N	WI	60,61	north of Guiana	11
027	5N	AU	50	north of Sumatra	17
027	5N	SP	50,58	north of Sumatra	04
030	5N	N.A.	65,54	INDIAN OCEAN	01
040	15N	SP	62	N. ATLANTIC	05
042	15N	WI	65	off Barbados	08
044	15N	AU	63	Caribbean	05
063	15N	WI	60,60	B. of Bengal	04
077	25N	AU	65	N. ATLANTIC	05
080	25N	SP	68	off Bahamas	10
080	25N	AU	69	off Bahamas	10
085	25N	WI	59	N. PACIFIC	23
110	35N	WI	57,60	N. ATLANTIC	05
111	35N	WI	60,70,55	N. ATLANTIC	06
115	35N	SP	69,65,65,60	off Bermuda	07
148	45N	AU	59,54	N. ATLANTIC	05
149	45N	SU	55	N. ATLANTIC	05
150	45N	SU	50	N. ATLANTIC	05
182	55N	SU	53	N. ATLANTIC	05
184	55N	SU	57	N. ATLANTIC	05
185	55N	SU	53	N. ATLANTIC	05
259	75N	AU	70,53	Baffin Bay	05
303	5S	SU	60	S. ATLANTIC	11
320	5S	AU	55,64,56,53,62	SOLOMON SEA	15
325	5S	SP	52,52,53,52,53	JAVA SEA	13
326	5S	AU	50	N. INDIAN OCEAN	17
329	5S	N.A.	56	near Chagos Arch	01
355	15S	AU	66	CORAL SEA	14
356	15S	AU	56,61,58,65,66	CORAL SEA	14
357	15S	AU	61	off CAPE YORK	17
359	15S	SP	52	TIMOR SEA	13
359	15S	AU	52,54,55,59	TIMOR SEA	04,15,14
360	15S	WI	60,60	JAVA TRENCH (east)	04,15
360	15S	AU	58,58,60,60	JAVA TRENCH (east)	17
361	15S	AU	60,57,59	JAVA TRENCH (west)	15
361	15S	SP	53	JAVA TRENCH (west)	15
390	25S	WI	57	TASMAN SEA	03
425	35S	WI	54,55	TASMAN SEA	03
426	35S	WI	61	TASMAN SEA	03
428	35S	WI	53,55,49	TASMAN SEA	03,22
428	35S	AU	49,46,52	Tasman Sea	13,14,17
428	35S	SU	52,51	TASMAN SEA	14
432	35S	SP	55	off C. Leeuwin	17
447	35S	N.A.	68	S. ATLANTIC	02
500	55S	SP	60	SOUTHERN OCEAN	

KEY

AU = AUTUMN  
WI = WINTER  
SP = SPRING  
SU = SUMMER  
N.A. = NOT AVAILABLE

HIGH  $S_c$   $-51 < S_c < -46$   
LOW  $S_c$   $-70 < S_c < -65$

TABLE 2

NIGHT COLUMN STRENGTHS IN MARSDEN SQUARE ORDER

MARSDEN SQUARE	LATITUDE	SEASON	COLUMN STRENGTH (NEGATIVE)	GENERAL LOCATION	REFERENCE
005	5N	WI	42,55	north of Guiana	11
027	5N	WI	48,48	north of Sumatra	04
030	5N	N.A.	49	INDIAN OCEAN	01
040	15N	SP	50	N. ATLANTIC	05
042	15N	WI	49	off Barbados	11
044	15N	AU	52	Caribbean	05
063	15N	WI	48,48	B. of Bengal	04
077	25N	AU	52	N. ATLANTIC	05
080	25N	SP	57	off Bahamas	10
080	25N	AU	59	off Bahamas	10
085	25N	WI	56	N. PACIFIC	23
110	35N	WI	59	N. ATLANTIC	05
111	35N	WI	43,54	N. ATLANTIC	06
115	35N	SP	44,42,44,50	off Bermuda	07
147	45N	AU	49,50	N. ATLANTIC	05
148	45N	AU	50	N. ATLANTIC	05
149	45N	SU	55	N. ATLANTIC	05
150	45N	SU	42	N. ATLANTIC	05
182	55N	SU	50	N. ATLANTIC	05
185	55N	SU	40	N. ATLANTIC	05
259	75N	AU	55	Baffin Bay	05
300	5S	SU	57	S. ATLANTIC	02
303	5S	SU	55	S. ATLANTIC	11
320	5S	AU	49,45,34,48	SOLOMON SEA	15
323	5S	WI	43	ARAFURA SEA	17
325	5S	SP	36,39,38,42	JAVA SEA	13
357	15S	AU	49	off CAPE YORK	17
359	15S	SP	43	TIMOR SEA	13
359	15S	AU	43,39,40,38,37	TIMOR SEA	13
360	15S	WI	49	JAVA TRENCH (east)	04,15
360	15S	AU	45,50,48,49,50	JAVA TRENCH (east)	17
360	15S	SP	44	JAVA TRENCH (east)	15
361	15S	AU	45,51,51,54,55	JAVA TRENCH (west)	15
361	15S	SP	43,39	JAVA TRENCH (west)	15
390	25S	WI	45	TASMAN SEA	03
425	35S	WI	50,47	TASMAN SEA	03
426	35S	WI	51	TASMAN SEA	03
428	35S	WI	45	TASMAN SEA	14
428	35S	AU	40,45,39	Tasman Sea	13,14,17
428	35S	SU	49,38,45	TASMAN SEA	14
430	35S	SP	41	GRT AUST BIGHT	17
431	35S	SP	43,35	GRT AUST BIGHT	17
432	35S	SP	49	off C. Leeuwin	17

KEY

AU = AUTUMN  
WI = WINTER  
SP = SPRING  
SU = SUMMER  
N.A. = NOT AVAILABLE

HIGH  $S_c$  -39 <  $S_c$  < - 34  
LOW  $S_c$  -59 <  $S_c$  < - 54

negative column strengths. 'High' and 'low' values for each of the tables are defined as those that lie within 5 dB of the maximum and the minimum column strengths respectively.

In Table 1 the 'high' day column strengths range in value from -51 to -46 dB, and the 'low' day column strengths range from -70 to -65 dB.

In Table 2 the 'high' night column strengths occur in the range from -39 to -34 dB; and the 'low' night column strengths range -59 to -54 dB.

The results presented in these tables will be discussed further in the section headed 'Geographical Variation'. The variation in column strengths between day and night values is apparent throughout the table where night column strengths can be as much as 10 dB higher than day column strengths.

An example is for MS 428 where day column strengths are -52, -55, -49, -51, -46, 52, -52, -49 dB; whereas night column strengths are -45, -40, -45, -39, -49, -38, -45 dB.

(b) Seasonal Variation

Day column strengths and their seasonal variation are presented in Table 3. Night column strengths are given in Table 4.

The seasons are defined as follows:

Hemisphere Months	North	South
3 - 5	Spring	Autumn
6 - 8	Summer	Winter
9 - 11	Autumn	Spring
12 - 2	Winter	Summer

TABLE 3

DAY COLUMN STRENGTHS (VARIATION WITH SEASON)

MARSDEN SQUARE	SEASON	COLUMN STRENGTH (NEGATIVE)	GENERAL LOCATION
027	SP	50,58	north of SUMATRA
040	SP	62	N. ATLANTIC
080	SP	68	off Bahamas
115	SP	65,65,65,60	off Bermuda
325	SP	52,52,53,52,53	Java Sea
359	SP	52	Timor Sea
361	SP	53	Java Trench (west)
432	SP	55	off C. Leeuwin
500	SP	60	SOUTHERN OCEAN
149	SU	55	N. ATLANTIC
150	SU	50	N. ATLANTIC
182	SU	53	N. ATLANTIC
184	SU	57	N. ATLANTIC
185	SU	53	N. ATLANTIC
303	SU	60	N. ATLANTIC
428	SU	52,51	Tasman Sea
027	AU	50	N. of Sumatra
044	AU	63	Caribbean Sea
077	AU	65	N. ATLANTIC
080	AU	69	off Bahamas
148	AU	59,54	N. ATLANTIC
259	AU	70,53	BAFFIN BAY
320	AU	62,55,64,56,53	Solomon Sea
326	AU	50	N. INDIAN
355	AU	56	Coral Sea
356	AU	56,61,58,65,66	CORAL SEA
357	AU	61	off Cape York
359	AU	52,54,55,59	Timor Sea
360	AU	58,58,60,60	Java Trench (east)
361	AU	60,57,59	Java Trench (west)
428	AU	49,56,52	TASMAN SEA
005	WI	60,61	north of Guiana
042	WI	65	off Barbados
063	WI	60,60	B. of Bengal
085	WI	59	N. PACIFIC
110	WI	57,60	N. ATLANTIC
111	WI	60,70,55	N. ATLANTIC
360	WI	60,60	Java Trench (east)
390	WI	57	Tasman Sea
425	WI	54,55	Tasman Sea
426	WI	61	Tasman Sea
428	WI	53,55,49	Tasman Sea

KEY: AS FOR TABLE 1

**TABLE 4**  
**NIGHT COLUMN STRENGTHS (VARIATION WITH SEASON)**

MARSDEN SQUARE	SEASON	COLUMN STRENGTH (NEGATIVE)	GENERAL LOCATION
040	SP	50	N. ATLANTIC
080	SP	57	off Bahamas
115	SP	44,42,44,50	off Bermuda
325	SP	36,39,38,42	Java Sea
359	SP	43	Timor Sea
360	SP	44	Java Trench (east)
361	SP	43,39	Java Trench (west)
430	SP	41	GREAT AUST. BIGHT
431	SP	43,45	GREAT AUST. BIGHT
432	SP	49	off C. Leeuwin
149	SU	55	N. ATLANTIC
150	SU	42	N. ATLANTIC
182	SU	50	N. ATLANTIC
185	SU	40	N. ATLANTIC
300	SU	57	S. ATLANTIC
303	SU	55	S. ATLANTIC
428	SU	49,38,45	TASMAN SEA
044	AU	52	Caribbean Sea
077	AU	52	N. ATLANTIC
080	AU	59	off Bahamas
147	AU	49,50	N. ATLANTIC
148	AU	50	N. ATLANTIC
259	AU	55	BAFFIN BAY
320	AU	49,45,34,48	Solomon Sea
357	AU	49	off Cape York
359	AU	43,39,40,38,37	Timor Sea
360	AU	45,50,48,49,50	Java Trench (east)
361	AU	45,51,51,54,55	Java Trench (west)
428	AU	40,45,39	
005	WI	42,55	north of Guiana
027	WI	48,48	N. of Sumatra
042	WI	49	off Barbados
063	WI	48,48	B. of Bengal
085	WI	56	N. PACIFIC
110	WI	59	N. ATLANTIC
111	WI	43,54	N. ATLANTIC
323	WI	43	ARAFURA SEA
360	WI	49	Java Trench (east)
390	WI	45	Tasman Sea
425	WI	50,47	Tasman Sea
426	WI	51	Tasman Sea
428	WI	45	TASMAN SEA

**KEY: AS FOR TABLE 2**

The results suggest that during the day there are generally higher overall  $S_c$  for the summer months. The lowest range of values of column strength occur in the autumn and spring.

Those Maraden Squares in the low latitudes would be expected to show little seasonal variation of column strengths. An example of this trend is MS 080 where there appears to be little seasonal variation. In spring it has a low  $S_c$  of -68 dB and again in autumn it has a similarly low  $S_c$  of -69 dB.

Night column strengths and their variation with season are shown in Table 4. The paucity of results prevents one from making a clear statement about the seasonal influence; but the column strengths overall appear to be lower in the spring than during the other seasons.

(c) Geographical Variation

The variation of day column strength with latitude is shown in Fig. 4. For this figure high values of day column strength are denoted by the symbol  $\blacktriangle$  and occur in the range  $-51 < S_c < -46$ . Low day column strengths are shown by  $\triangle$  and these occur in the range  $-70 < S_c < -65$ . Fig. 4 shows 'high' day scattering at 3.5 kHz in the south-east Australian region (MS 428). There is low scattering during the day at middle latitudes in the North Atlantic (MS 080, 077 and 115).

The variation of night column strengths with latitude is shown in Fig. 5. As was the case in the previous figure, 'high' column strengths are denoted by the symbol  $\blacktriangle$ , and low column strengths are shown by the symbol  $\triangle$ . However, for this figure, 'high' night column strengths occur in the range  $-39 < S_c < -34$ .

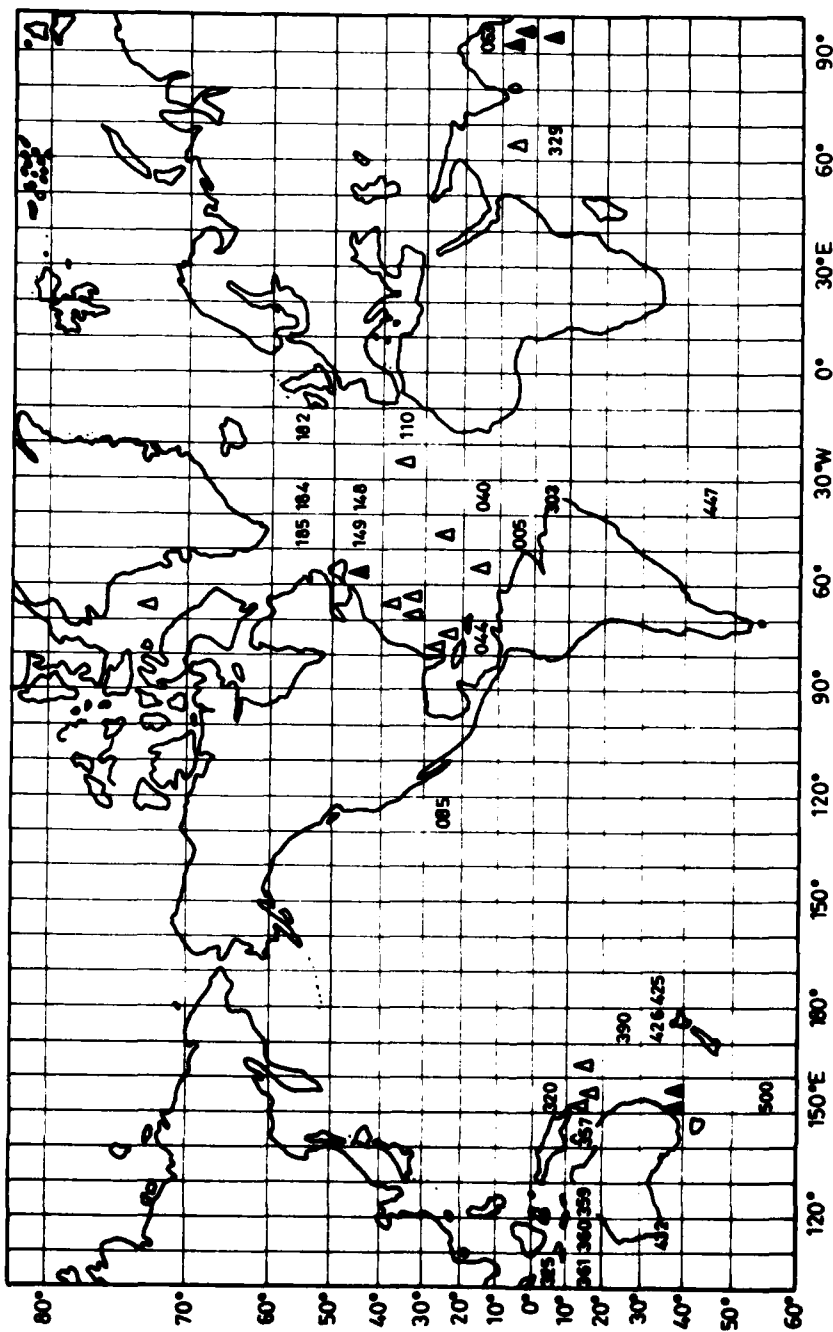


Fig. 4. Map of World showing 'high' day column strengths  $\Delta[-51 < S_c < -46]$  and 'low' day column strengths  $\Delta[-70 < S_c < -65]$  at 3.5 kHz.

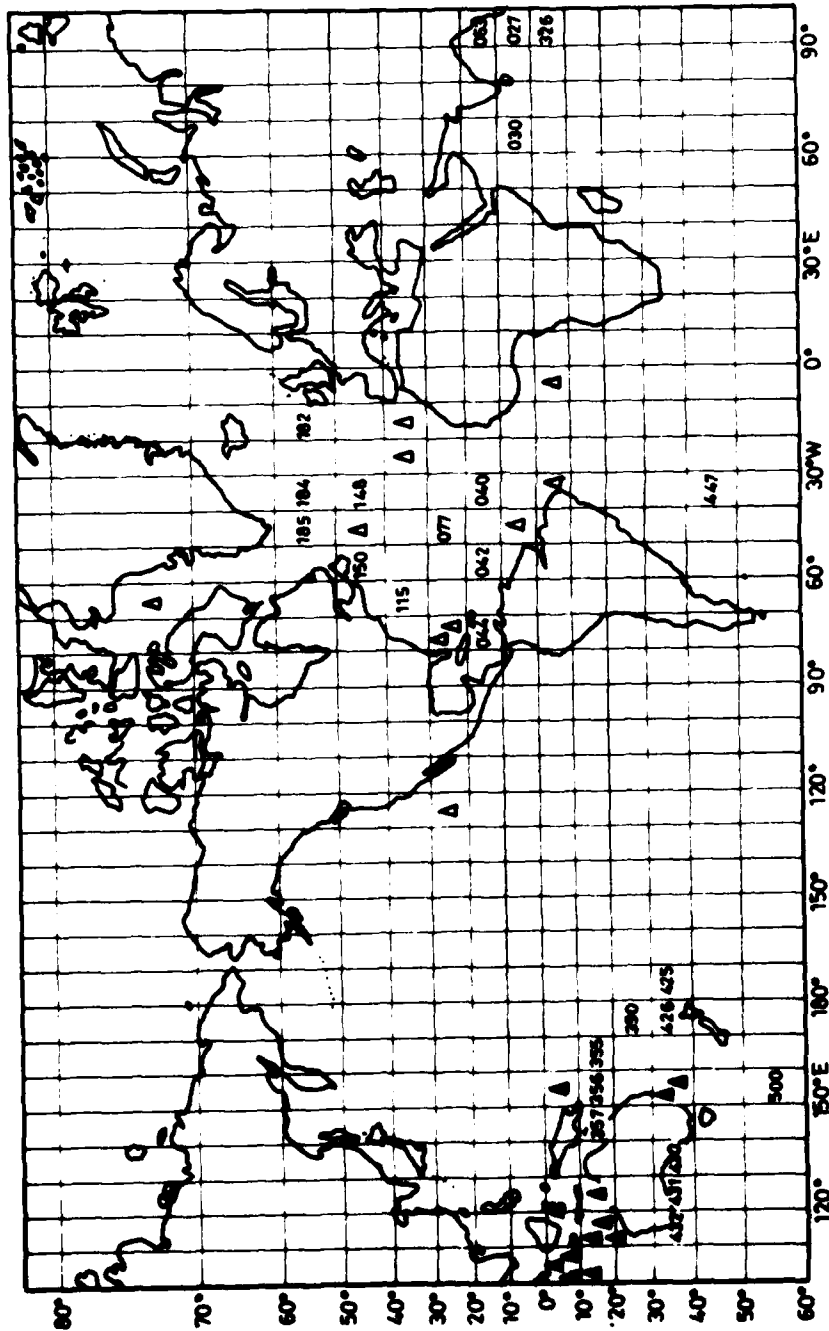


Fig. 5. Map of World showing 'high' night column strengths  $\Delta$   $[-39 < S_c < -34]$  and 'low' night column strengths  $\Delta$   $[-59 < S_c < -54]$  at 3.5 kHz.

and 'low' night column strengths occur in the range  $-59 < S_c < -54$ .  
The night column strengths show a trend towards high scattering  
in the Australasian waters (MS 428, 359 and 361); and for low  
column strengths to occur in the North Atlantic (MS 080, 110 and 085).

## 5. DISCUSSION

- (a) Various mechanisms confound the prediction of column strength between adjacent mardden squares. Local processes, such as mixing of water types containing different biological communities, patchiness and random variabilities are operating. For example, the column strength for MS 428, an area in which Tasman Sea mesopelagic eddies commonly occur, would have a value largely influenced by whether or not an eddy was present at the time of survey.

Hydrographic features alone however are unlikely to be the only cause of significant differences in column strength, biological features such as species migration may be equally important.

Many more volume scattering experiments must be performed, particularly in the regions of known faunal boundaries before it will be feasible to divide the world's oceans into reverberation provinces.

## 6. CONCLUSIONS

- (a) There is significant diel variation in sound scattering at 3.5 kHz, with night column strengths generally 10 dB higher than day levels. A comparison between the day and night column strengths shown in figures 4 and 5 show similar zones of high scattering. The maximum daytime column scattering strength is -46 dB (MS 428) and the minimum daytime value is -70 dB (MS 239, 111). The maximum night-time value of  $S_c$  is -34 dB (MS 320), and the minimum night-time value is -59 dB (MS 080, 110).

- (b) Day column strengths at 3.5 kHz are greatest north-west and south-east of Australia and in the high latitudes of the North Atlantic Ocean. Minimum values occur north-east of Australia and in the low latitude regions of the North Atlantic Ocean.
- (c) Night column strengths at 3.5 kHz are greatest in the tropical waters north of Australia and in the Tasman Sea off the south-east coast of Australia. Low night column strengths at 3.5 kHz are found in the north Atlantic.

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